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Microphysical and radiative transfer model of the lower, middle, and upper clouds of Venus

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Abstract

A model exhibiting the role of the radiative dynamical feedback in the maintenance of the middle and lower clouds of Venus was previously developed and demonstrated by McGouldrick and Toon [1]. That work incorporated a microphysical model of the Venus lower and middle clouds similar to that of James et al. [2], but also included radiative transfer in both the visible and infrared to compute a time-dependent vertical temperature profile. As the radiative heating altered the static stability of the vertical profile, a parameterization of the eddy diffusion coefficient, based on the Richardson Number, was used to incorporate the effects of vertical transport due to convection. This paper represents the initial results of follow-up work to that project, in which the model previously used by McGouldrick and Toon is extended to include the physics of the region of the upper clouds and hazes of the Venus atmosphere (i.e., altitudes between 60km and 100km).

1. Introduction

The Venusian cloud system is a three-layered cloud deck with areas of diminished particle concentration (traditionally referred to as upper and lower hazes) both above and below (Fig. 1). The upper cloud, found between about 57km and 70km, forms photochemically from SO_2 and H_2O. The SO_2 may be the product of volcanism, or may be the result of other sulfur gases in thermo-chemical equilibrium with surface rocks. SO_2 is likely recycled from the deep atmosphere below about 40km where thermal chemistry dissociates the sulfuric acid back into its components (H_2O and SO_2). The upper cloud forms a fairly homogeneous but diffuse cloud layer, similar in terms of global coverage to that exhibited by the photochemical hydrocarbon haze on Titan. Below about 57km, the vapor pressure of sulfuric acid and water over the cloud particles is relatively high, and therefore sulfuric acid clouds can evaporate in a relatively short period of time. As a consequence, the lower and middle cloud decks contain condensational clouds that are highly variable. The lower haze (not shown in Fig. 1) extends from the cloud base down to about 40km, and is likely a collection of involatile particles, which likely serve as condensation nuclei for the lower and middle cloud particles. The upper haze, on the other hand, extends from the upper clouds to about 90km and is likely composed of sub-micron sulfuric acid particles.

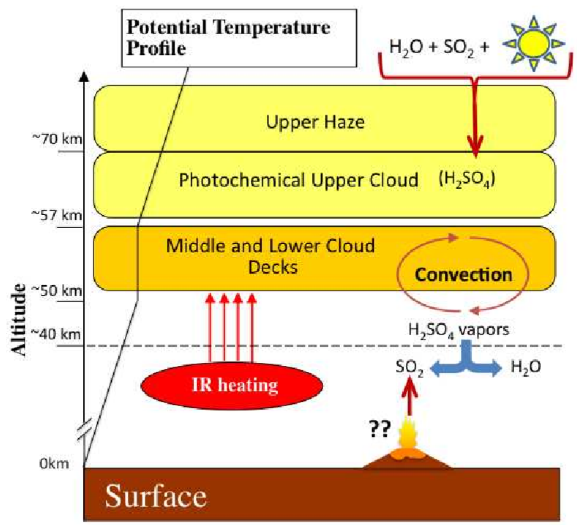

Figure 1: A schematic figure of the Venus atmospheric clouds and hazes.

The constituents of the upper atmosphere of Venus have exhibited significant variability. A large and long-term variation in the cloud-top SO_2 concentration, evident both from spacecraft observations and from Earth-bound rocket observations, was noted during the *Pioneer Venus* mission [3]. Recent observations from the Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Venus/ Solar Occultation at Infrared (SPICAV/SOIR) instrument on *Venus Express* indicate that the SO_2 concentrations in the Venus mesosphere have returned to early *Pioneer Venus* levels [4], but Earth-based observations suggest otherwise [5]. Regardless of the present conditions of SO_2 in the upper atmosphere of Venus.

Re-analysis of *Pioneer Venus* OIR data indicated order of magnitude diurnal variation in the above-cloud water vapor concentrations [6]. As with SO_2, because of its role in the formation of the sulfuric acid of which the Venus clouds are composed, variations in H_2O can have significant and observable consequences for the Venus upper clouds and hazes. In addition, since water is usually more abundant than sulfuric acid in the vapor phase, solutions of sulfuric acid and water rapidly come into an equilibrium whereby the concentration of the acid is often determined by the environmental water vapor concentration. The saturation vapor pressure of sulfuric acid over the particles in solution with water is a function of the equilibrium acid mass fraction [7], as is the particle refractive index [8]. Thus, changes in the concentration of water vapor can result in changes in the growth properties and radiative properties of the sulfuric acid droplets that make up the clouds of Venus.

2. Improvements to the model

Our previous work considered only the globally averaged solar heating profile as calculated from the solar flux profile observed by the *Pioneer Venus* Solar Flux Radiometer. Since the obliquity of Venus is approximately zero degrees, the average insolation at a latitude of about 40 degrees equals the globally averaged insolation of Venus. Thus, our previous work is most consistent only with the behavior of the atmosphere at mid-latitudes; and somewhat less consistent with the atmosphere at equatorial and polar latitudes. In addition, recent investigations have shown that there is significant latitudinal variation to the behavior of the clouds of Venus [9]. Furthermore, the amount of variation in the Venus cloud cover increases with proximity to the equator [9]. By exploring the latitudinal and temporal variability in the insolation, we can investigate to what extent these variations affect the observed spatial and temporal variability in the cloud cover.

The observed variations in SO_2 and H_2O will manifest themselves also as variations in these clouds and hazes. We have begun to implement a simple parameterization of the photochemistry occurring in the upper atmosphere of Venus in order to investigate the relationships and feedbacks involved in the formation of the upper clouds and hazes.

This presentation will discuss the progress made toward the implementation of these photochemical and diurnal effects on the cloud model of McGouldrick and Toon across a larger vertical domain than had been implemented in those earlier works.

Acknowledgements

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